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Effect of turbine materials on power generation efficiency from free water vortex hydro power plant

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Abstract. The objective of this research was to study the effect of turbine materials on power generation efficiency from the water free vortex hydro power plant made of steel and aluminium. These turbines consisted of five blades and were twisted with angles along the height of water. These blades were the maximum width of 45 cm. and height of 32 cm. These turbines were made and experimented for the water free vortex hydro power plant in the laboratory with the water flow rate of 0.68, 1.33, 1.61, 2.31, 2.96 and 3.63 m^3/min and an electrical load of 20, 40, 60, 80 and 100 W respectively. The experimental results were calculated to find out the torque, electric power, and electricity production efficiency. From the experiment, the results showed that the maximum power generation efficiency of steel and aluminium turbine were 33.56% and 34.79% respectively. From the result at the maximum water flow rate of 3.63 m^3/min, it was found that the torque value and electricity production efficiency of aluminium turbine was higher than that of steel turbine at the average of 8.4% and 8.14%, respectively. This result showed that light weight of water turbine can increase the torque and power generation efficiency.

1. Introduction

At the present the turbines have been developed with the different sizes and figures and with high effectives. These turbines are most important components for hydro power plant because they can transform the kinetic energy into mechanical energy of water to make turbines rotation and it results in rotation of the axis for connected generator. This process leads to electricity production. The turbines can be classified into two types consisted of Impulse turbine and Reaction turbine [1].

The water free vortex is a power seriously studied and brought for electricity production [2-4]. There is using the process of increasing the kinetic energy in the natural water flow for being higher power with throwing water into the rim of whirlpool. And the effect of water flows into pipe with the holes parched in the bottom causing the flow of free water vertex. This makes water has a higher speed from the influence of the Earth's gravity having the maximum speed of water tide on the radius of free water vertex [2-10]. According to the rule of angular momentum, more there are many radiuses of whirlpool and rate of water flow, more there are angular momentums also. When water flows into the turbine, the angular momentum of water will be transformed as torque values to rotate generator and to product the electricity [11].

According to Sujate and Ratchaphon [2], they studied Design and Development of Water Free Vortex Micro Hydro Power Plant [2-10] and found that turbines could produce the electricity using five blades made of steel twisted with angle along the height of water [2, 11]. However, this research was found the problem about the weight of steel because it must spend much power for rotation turbines. So, this research was aimed to adapt the materials for making turbines to have lighter weight and to study the effect of turbine materials on power generation efficiency from the water free vortex hydro power plant.

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2. Theory for experimentation

2.1. Force and velocity of water

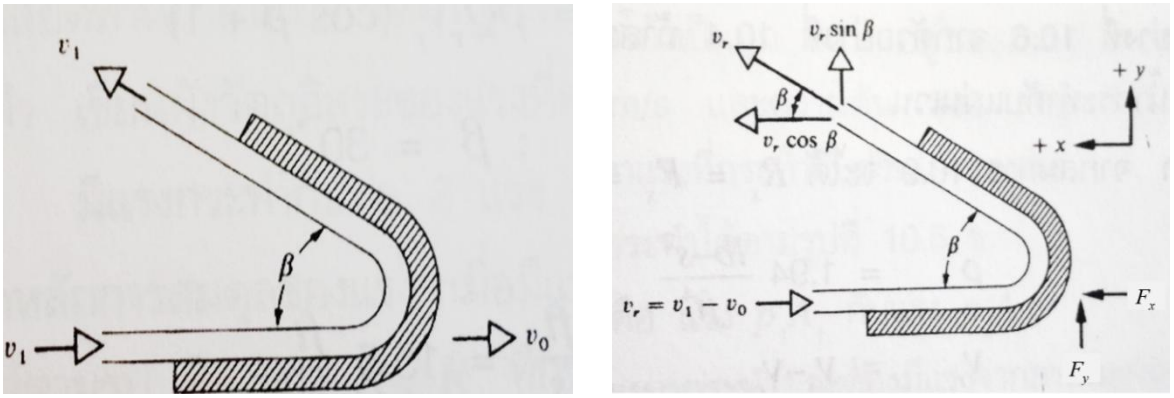
According to figure 1, the power of water could affect blades when water tides flowed against with rotating turbine. If the rapidity of water was more than the rapidity of turbine, the water power could flow against with blades affects acceleration. Then water turbines would rotate and there was relative movement between liquid and moving materials affecting to have power. The rapidity of liquid related to moving objects could be written as this following equation [12]:

$$F = \sqrt{F_x^2 + F_y^2} \tag{1}$$

$$F_x = \rho Q_r V_r (cos\,\beta + 1) \tag{2}$$

$$F_y = \rho Q_r V_r (sin\,\beta) \tag{3}$$

$$V_r = V_1 - V_0 \tag{4}$$



(a) Moving of Venn Plate (b) Unmoving of Venn Plate

Figure 1. Showing power of water affecting turbine [12].

When F = Force turbine

F_x = Force of flowing water affecting turbine in axis X

F_y = Force of flowing water affecting turbine in axis Y

V_r = Relative Velocity

V_1 = Velocity of flowing water against with moving materials

V_0 = Turbine velocity motion

β = Angle of water turbine

2.2. Torque and power

Torque values and power received from this energy could be calculated from this following equation [11]:

$$P_m = \rho g Q H \tag{5}$$

$$T = \frac{60 P_m}{2\pi N} \tag{6}$$

When ρ = density of water 1,000 kg/m^3

g = acceleration from earth's gravity 9.81 m^2/s

Q = water flow rate (m^3/min)

P_m = Power from hydro power (W)

T = Torque of water turbine (Nm)
N = rotation a speed (rpm)
H = Height of water (w)

2.3. Power generation efficiency (η)

The efficiency of electric system could be calculated from the rate between real powers received from electricity with mechanical power. It could be found from this equation [13]:

$$\eta = \frac{P_e}{P_m} \tag{7}$$

According to

$$\mathrm{P_e} = \mathrm{EI} \tag{8}$$

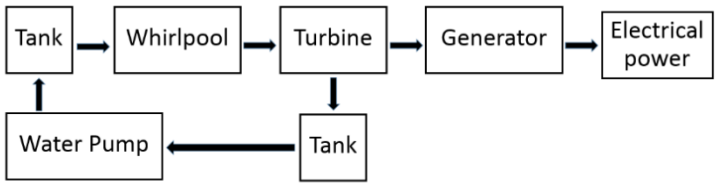
When *E* = Voltage (V)
I = *E*lectric current (A)
P_e = Electrical power (W)

3. Instruments for experimentation and experimental methodology

3.1. Instruments for experimentation

Small generator from water free vortex hydro power plant in the laboratory according to the figure 2 consisted of four parts:

(a) The real working photo in the laboratory



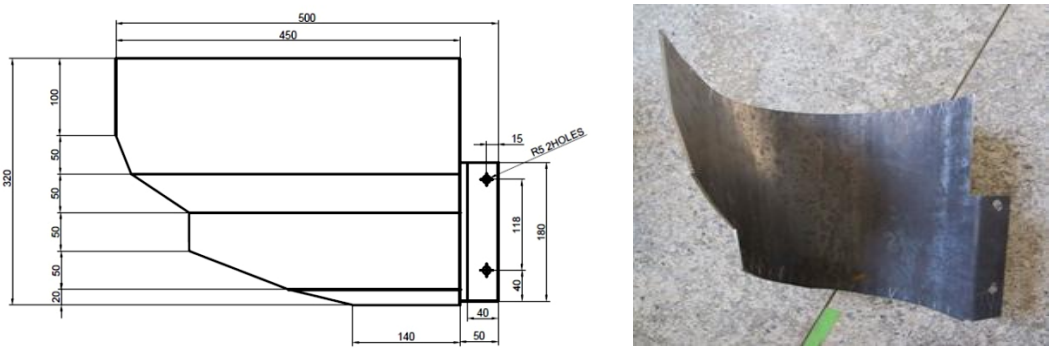
(b) Working diagram

Figure 2. System of small electricity production from the free vortex hydro power plant [3].

- A water tank size on the top with of 1.5 × 1.5 × 1.2 m. was connected to gutter.
- Vortex pond consisted of diameter 1 m. and height 1 m. The bottom of pond had water hole of diameter 0.2 m.
- Lower reservoir.
- Five water pumps could control the value of water flow rate during 0.65-3.63 m^3/min.
- The steps of experimentation consisted of using turbines made of steel and aluminium. These turbines consisted of 5 blades and were twisted angle along the height of vertex water [2]. The figures of water turbines made of steel and aluminium was shown in table 1. These turbines were the maximum width of 45 cm. and height of 32 cm. A figure of single turbine could be seen in figure 3 and construction of water turbines was in figure 4.

Table 1. A comparative property of steel (Fe) and aluminum (Al) materials.

Material	Density (kg/m^3)	Young's modulus (Pa)	Shear modulus (Pa)	Poisson Ratio	Max. stress × 10^7 Pa	Weigh of turbine (kg)
Fe	7,830	196.5	76	0.3	35	14.894
Al	2,700	68.95	26	0.33	14	6.184



(a) A drawing form of turbine (b) Real turbine

Figure 3. Figures of water turbine for the test [2].

(a) Steel turbine (b) Aluminum turbine

Figure 4. Figures of turbines were set in the small generator from the free water vortex hydro power plant.

3.2. Experimental methodology

The experimental methodology consisted of using steel turbine was set in the vertex water of small generator from the free water vortex hydro power plant in the laboratory. (According to figure 2) For this experimentation, there was setting the water flow rate flowed to turbines with the water flow rate of 0.98, 1.33, 1.61, 2.31, 2.96 and 3.63 m^3/min respectively using electric load size of 5 incandescent of 20 W.

The experimentation was set the water flow rate of 0.98 m^3/min and connected to the electricity production system at size load of 20 W. After that there was measurement of water height, number of axel rotation round, generator, voltage, and electric current received from the generator system. Later there was a number of load as 40, 60, 80 and 100 W respectively and recorded the values and there was repeated experimentation changed flowing rate as they were set. After that changing blade of aluminum turbine and set it in the small generator from the water free vortex hydro power plant according to figure 4. Then there was experimentation as the case of steel turbine and recorded the values. At last brought the values received from experimentation to calculate the value of electric power, power of electric flowing and torque value of turbine and efficiency of electricity production.

4. Result of experimentation

4.1. The speed of turbines

According to figure 5, it was found that the low flow rate affected a round speed of aluminum turbine rotation much more than steel turbine. However, when there was increasing of the much load and flow rate, the round speed of turbine rotation was equal values. According to result analysis, it made us know that if there was increasing much flow rate, there was higher power of water affecting turbine. So, the different results of round speed happened from weight of turbine would be less and if the power of water affected turbines which had very high value. It could make the equal round speed of turbine rotation. The result was related with the equation of flow power affected material moving if it

was set as $Q_r = Q_1 = Q_2$ and $\beta = \beta_1 = \beta_2$ when Q_1 = the water flow rate was used with steel turbine, Q_2 = the water flow rate was used with aluminum turbine, β_1 = angle in steel turbine and β_2 = angel in aluminum turbine. This equation could be written as (1), (2) and (3) as these followings:

$$\sqrt{[\rho Q_1 V_{r1}(\cos\beta_1 + 1)]^2 + [\rho Q_1 V_{r1}(\sin\beta_1)]^2} = \sqrt{[\rho Q_2 V_{r2}(\cos\beta_2 + 1)]^2 + [\rho Q_2 V_{r2}(\sin\beta_2)]^2}$$

$$(\rho Q_r)^2(V_1 - V_{0Fe})^2[(\cos\beta + 1)^2 + (\sin\beta)^2] = (\rho Q_r)^2(V_1 - V_{0Al})^2[(\cos\beta + 1)^2 + (\sin\beta)^2]$$

$$V_{0Fe} = V_{0Al} \quad (9)$$

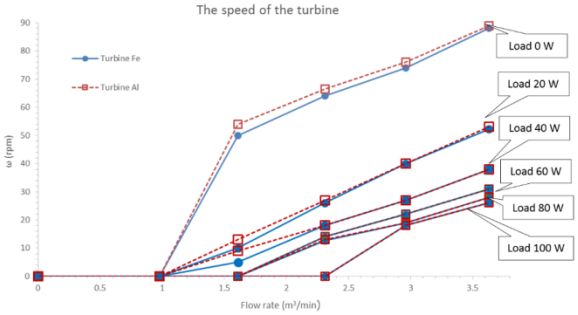


Figure 5. A comparative round speed of both turbine made of steel and aluminum.

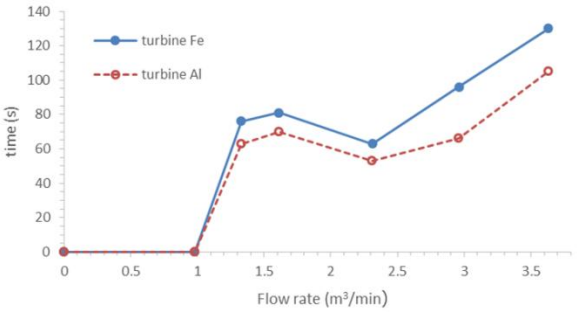


Figure 6. Time for moving of turbines from stopping points to highest speed of other flow rates.

According to the equation, it could explain that the highest speed of steel and aluminum rotation was the equal rapidity which was not depending on the materials for making turbines.

According to figure 6, the result was found that the steel turbine spent time for first moving to the highest speed much more than all flow rates of aluminum turbine. This result could analyze that the same flow rate and water power affected both turbines which were equal values. The weight of steel turbine was much more than aluminum turbine affected time which was spent for moving of turbine to the highest speed. It could spend much time than aluminum turbine. This resulted in long time for electricity production. This experimental result was related with theory of Newton's motion said that, "an object will only accelerate if there is a net or unbalanced force acting upon it". It got from this relation of $F = mg = m\Delta v\Delta t = m\Delta v$ [12]. It was set X as fixed rate and $X \geq 1$ *so,* $m_1 = Xm_2$ by m_1 was mass of steel turbine and m_2 was mass of aluminum turbine and it was analyzed as the same flow rate became $m_1 = m_2$

$$\frac{m_1}{\Delta t_1} = \frac{m2}{\Delta t2}$$

$$\Delta t_1 = X\Delta t_2 \quad (10)$$

It was found that when Δt_1 was time for moving steel turbine which was higher speed than spent time of aluminum, so Δt_2 was related with experimentation on figure 6.

4.2. Torque values and power

According to the experimental table 2, it could be calculated to find out the torque values of turbine from equation (6) and electric power from equation (8). The water flow rate of 0.98 m^3/min could not have electric power and torque values because the water power was not enough for turbine rotation with the same load value. When the value of water flow rate increased, it would have electric power and torque values got from the both turbines could increase. This result showed the value of electric power and torque changed as the value of water flow rate. The value of electric power received from aluminum turbine was higher value than steel turbine. At the flow rate at 3.63 m^3/min, the power using aluminum turbine was between 21.14–51.62 W, while the power using steel turbine was 19.98–49.8 W. This result came from the different weight of aluminum for making turbine which had less weigh than steel turbine.

Table 2. The result of experimentation to find out the torque power and efficiency.

Flow rate	Load	H		Turbine Torque (Nm)		Water power (W)		Electrical power (W)		Efficiency	
(m^3/min)	(W)	Turbine Fe	Turbine Al	Turbine Fe	Turbine Al	Turbine Fe	Turbine Al	Turbine Fe	Turbine Al	Turbine Fe	Turbine Al
1.61	20	0.29	0.33	2.03	6.15	76.34	86.87	2.13	3.31	2.8%	3.81%
	40	0.30	0.34	1.26	5.30	78.97	89.50	0.66	1.19	0.8%	1.33%
	60	0	0	0	0	0	0	0	0	0%	0%
2.31	20	0.33	0.31	6.02	7.31	124.64	117.08	16.39	20.83	13.15%	17.79%
	40	0.34	0.34	5.17	5.41	128.41	128.41	9.20	10.20	7.16%	7.94%
	60	0.36	0.34	3.58	4.04	135.97	128.41	5.24	5.92	3.85%	4.61%
	80	0.36	0.34	2.83	3.20	135.97	128.41	3.74	4.36	2.75%	3.40%
	100	0	0	0	0	0	0	0	0	0%	0%
2.96	20	0.25	0.24	6.16	8.04	120.99	116.15	25.80	33.66	21.32%	28.98%
	40	0.29	0.27	7.19	7.87	140.35	130.67	20.49	22.26	14.60%	17.04%
	60	0.30	0.29	5.64	7.07	145.19	140.35	13.00	16.29	8.95%	11.61%
	80	0.31	0.30	4.89	6.19	150.03	145.19	9.73	12.32	6.49%	8.49%
	100	0.31	0.30	4.11	4.95	150.03	145.19	7.74	9.33	5.16%	6.47%
3.63	20	0.25	0.25	9.11	9.30	148.38	148.38	49.80	51.62	33.56%	34.79%
	40	0.30	0.31	9.83	11.45	178.05	183.99	39.12	45.57	21.97%	24.77%
	60	0.32	0.32	9.47	9.98	189.92	189.92	30.73	32.38	16.18%	17.05%
	80	0.33	0.32	8.26	9.19	195.86	189.92	24.22	26.94	12.36%	14.18%
	100	0.34	0.33	7.34	7.76	201.79	195.86	19.98	21.14	9.90%	10.79%

4.3. The total efficiency

According to figure 7, it showed the total efficiency of electricity production received from steel turbine and aluminum turbine with the highest flow rate of 3.63 m^3/min and electric power 20 W which was valuable as 33.56% and 34.79% respectively. This result showed that the total efficiency was received from the test of both turbines was very close value. The total efficiency of aluminum turbine was higher than steel turbine. Moreover, the trends of total efficiency increased when the flow rate increased as figure 8 and it was found that the electric efficiency increased when there were fewer loads.

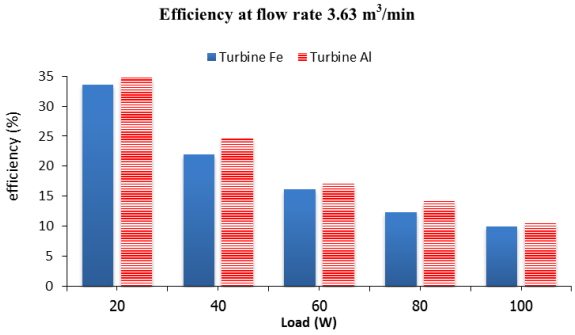


Figure 7. The total efficiency of the both turbines which had water flow rate of 3.63 m^3/min.

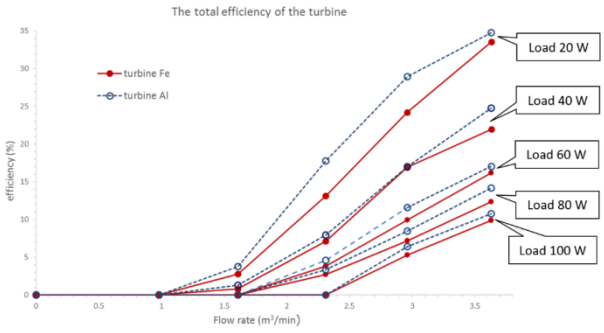


Figure 8. The total efficiency of both turbines which was different load values.

5. Conclusion

Changing materials to make light weight of water turbines with the unchanged size and figures could increase the efficiency of electricity production. According to the experimentation at the highest flow rate of 3.63 m^3/min, the maximum efficiencies of the steel and aluminum turbine were 33.56% and 34.79% respectively. It was found that the torque value and electricity production efficiency of aluminum turbine was higher than that of steel turbine at the average of 8.4% and 8.14% respectively. Moreover, aluminum turbine could spend the less time for moving of the highest speed than the equal

round speed because the weight of aluminum turbine was lighter than steel turbine. So, we could conclude that the materials for making the turbines were effective for electricity production.

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References
[1] Natthawut J and Chirakarn S 2010 Performance testing of a vertical axis water TURBINE with friction reduction: Blade performance comparison *The 9th National Kasetsart University Kamphaena Sean Conference* (Chonburi, Thailand: University of Kasetsart) pp 121-128
[2] Sujate W 2014 Design and development of water free vortex micro hydro power plant (University of Khon Kaen, Khon Kaen, Thailand: PhD thesis)
[3] Sujate W, Ratchaphon S and Sujin W 2013 A parametric study of a gravitation vortex power plant *Advanced Materials Research* **805-806** 811-817
[4] Sujate W and Ratchaphon S 2012 *Preliminary Design of a Vortex Pool for Electrical Generation Advanced Science Letters* **13** 173-177
[5] Zhao Y Z, Gu Z L and Yu Y Z 2003 Numerical analysis of structure and evolution of free water vortex *Journal of Xi'an Jiaotong University* **37** 85-88
[6] Granger R 1966 Steady three-dimensional vortex flow *Journal Fluid Mechanics* **25** 557-576
[7] Anwar H O 1965 Flow in a free vortex *Journal of Water Power* **17** 153-161
[8] Gordon J L 1970 Vortices at vertical intakes *Water Power* **4** 137-8
[9] Reddy Y R and Pickford J A 1972 Vortices at intakes in conventional sumps *Water Power* **3** 108-109
[10] Chen Y L, Wu C and Ye M 2007 Hydraulic characteristics of vertical vortex at hydraulic intakes *Journal of Hydrodynamics* **19** 143-149
[11] Nut P and Ratchaphon S 2014 A study of Torque and hydro turbine efficiency from free vortex energy *The 15th Graduate Research Conferences* (Khon Kaen, Thailand, University of Khon Kaen) pp 273-278
[12] Komsun W 2004 *Fluid Mechanics* (Thailand: Odean stone publisher) pp 215-223
[13] Giorgio R 2011 *Principles and Applications of Electrical Engineering* 5th edn (Mc Graw Hill , New York, International Enterprise Inc.) 566